APPENDIX 9-2

SEEPAGE EVALUATION
TASK 5.3.1.9.2 GROUNDWATER MODEL MEMORANDUM

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BLACK & VEATCH

TECHNICAL MEMORANDUM

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Task 5.3.1.9.2 Groundwater Model Memorandum
Seepage Evaluation

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1. INTRODUCTION

In October 2003, South Florida Water Management District (District) decided to pursue a "Dual Track" for the Everglades Agricultural Area (EAA) Reservoir project. While the multi-agency Project Delivery Team, led by the US Army Corps of Engineers (USACE), continues to develop the Project Implementation Report, the District is proceeding with the design of a reservoir (designated EAA Reservoir A-1 Project) located on land acquired through the Talisman exchange in the EAA.

The purpose of the EAA Reservoir Project as defined in the Comprehensive Everglades Restoration Plan (CERP) is to capture and store EAA Basin runoff and releases from Lake Okeechobee. The facilities will be designed to improve the timing of environmental water supply deliveries to Stormwater Treatment Areas 3 & 4 (STA 3/4) and the Water Conservation Areas (WCAs), reduce Lake Okeechobee regulatory releases to the estuaries, meet supplemental agricultural irrigation demands, and increase flood protection within the EAA.

EAA Reservoir A-1 will be located in Palm Beach County about 14 miles south of Lake Okeechobee along the North New River (NNR) Canal, as shown on Figure 1. The reservoir will be trapezoidal in shape, and at a depth of 12 ft it will have a storage volume of approximately 190,000 acre-ft. Reservoir dimensions will be refined through the design process, with provisions to control waves generated by wind action. Several gates are being evaluated along the perimeter embankment for the purpose of releasing water from the reservoir to the canals for irrigation and environmental demands. Several pump stations are being evaluated for the purpose of filling the reservoir by pumping water from the NNR Canal and potentially from the STA 3/4 Supply Canal. Seepage will occur from the reservoir and will be controlled by a combination of cutoff walls, seepage collection canals, and recirculation pumps.

2. OBJECTIVE OF THIS MEMORANDUM

The purpose of this technical memorandum is to provide an evaluation of seepage from the proposed reservoir and estimate the impacts on surrounding areas, specifically the agricultural areas, STAs, WCAs, US Highway 27, and Holey Land Management Area (Holey Land). The interaction between EAA Reservoir A-1 and the underlying aquifer was simulated using a groundwater model created using the Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW) code, developed by the US Geological Survey. Throughout the development of this model, there has been significant coordination between the District and the USACE, and this coordination will continue as we refine the model.

EAA Reservoir A-1 will experience large water level fluctuations each year, as shown in the example given by Figure 2. The reservoir will normally be filled during the wet season (June – October) when water is available in the major canals and will normally be emptied during the dry season (November – May) to supply water for agricultural and environmental purposes. The seepage rate will be proportional to the depth of water in the reservoir. In the hypothetical example shown by Figure 2, seepage will be greatest in January and February. A portion of the seepage will be collected by a new seepage canal that will be constructed around the perimeter of the reservoir, and a portion of the seepage will be collected by major canals such as the NNR Canal and the STA 3/4 Supply Canal. Seepage pumps will be designed to return the seepage collected by the canals back to the reservoir. Seepage not collected by the canals will flow to the surrounding areas including the farm lands, STA 3/4, and Holey Land.

A representation of anticipated seepage flow paths is illustrated on Figure 3. Any seepage that bypasses the seepage canal during the dry months may provide a benefit for the surroundings areas; seepage that migrates to these areas during the wet months may pose some adverse effects. In some instances, the farm canals may need to be pumped more than normal to return the seepage back to the NNR Canal to maintain acceptable groundwater levels for growing crops.

Because of the uncertainties associated with the variability in weather, demands for water, the operation of the canals, and the filling and emptying of EAA Reservoir A-1, this evaluation focuses on maximum seepage rates that will occur assuming equilibrium is established for a given set of conditions in and around the reservoir. This technical memorandum provides estimates of seepage to help answer the following questions:

- What is the rate of seepage that occurs from the reservoir at various reservoir water depths, cutoff wall depths, and seepage canal depths?
- What is the rate of seepage that is collected by the seepage canal so pumps can be designed to return this flow back to the reservoir?
- What is the rate of seepage that bypasses the seepage canal and is collected by the North New River and the STA 3/4 Supply Canals?
- What is the rate of seepage that bypasses the North New River and STA 3/4 Supply Canal and migrates to the farm lands, STA 3/4 , and Holey Land?

3. SCOPE

The overall scope of services for the groundwater flow modeling includes the following tasks:

- Obtain and review data – This task also involved collection and interpretation of aquifer stratigraphy, hydrogeology, water levels, and aquifer characteristics for use in the EAA A-1 groundwater flow model. The results of the recent test cell program, the USACE ongoing study, and several other past studies were reviewed to obtain information for the model

- Define model limits – This task involved defining the vertical and lateral model boundaries, model layers, and cell discretization
- MODFLOW model development – Using the results of the first two tasks, this task involved compiling the data and developing the groundwater flow model. Models were developed for both existing (pre-reservoir) conditions and various future conditions based on the proposed reservoir configuration alternatives
- Conduct initial reservoir simulations – This task involved initial model startup by working through a variety of issues associated with the input parameters and performing many verification analyses to determine the sensitivity of the model to these input parameters
- Information for Design Teams – Preliminary findings from these initial seepage simulations were provided to the various project teams to assist in the early stages of the reservoir conceptual design. Reservoir seepage will affect the results of the water balance of the A-1 reservoir, canal hydraulics, and pump station capacities
- Calibrate hydraulic conductivity values for the model – A Test Cell Program was conducted in 2005 within the footprint of the proposed reservoir (see Figure 1). The Test Cell Program produced data including seepage rates from, and water levels in, two test cells and canal and aquifer water levels surrounding the test cells. As part of Work Order No. 2, two-dimensional SEEP/W modeling was performed to evaluate the data to determine hydraulic conductivity values for the aquifer layers. Parallel to that effort, in an attempt to verify and support the SEEP/W model results, a small-scale, three-dimensional MODFLOW model was also developed for the test cells. This MODFLOW model was also used to calibrate the hydraulic conductivities of the underlying aquifer layers
- Evaluate alternatives – Based upon the results of the above tasks, various alternative reservoir configurations and canal conditions were evaluated to identify the most effective method to control seepage from the reservoir and minimize impacts to surrounding areas. The results of these model simulations are also being used to determine the impacts of various storage times, water depths, reservoir filling cycles, and drawdown cycles, as well as aiding in the determination of seepage collection and return pumping.

4. DATA SOURCES

Several sources of data were obtained and reviewed to develop an initial understanding of the hydrogeologic framework of the aquifer beneath the proposed reservoir area. These sources included:

- Black & Veatch. Test Cell Program. Work Order No. 2. April – May, 2005.
- Bureau of Geology. *Appraisal of the Water Resources of Eastern Palm Beach County, Florida.* Report of Investigations No. 67. 1973.
- Central and Southern Florida Flood Control District. *Seepage Investigation for the Holey Land*. December, 1975.

- *Central and Southern Florida Project, Comprehensive Everglades Restoration Plan, Everglades Agricultural Area Storage A-1 Reservoir Levee Optimization, Report for Conceptual Levee High Alternatives.* May 2004.
- Dames & Moore. *Factual Report Submittal, Offsite Seepage Study, Stormwater Treatment Area 2.* Prepared for SFWMD. January 21, 2000.
- SFWMD, USACE, Kimley-Horn and Associates. *Comprehensive Everglades Restoration Plan, Central and Southern Florida Project. B.2 Hydraulics, B.2.3 Hydrologic Model Calibration and Verification, Everglades Agricultural Area Storage Reservoirs – Phase 1.* January 2004.
- Stormwater Treatment Area No 3 & 4. *Plan Formulation Document*. 2000.
- USACE. Project Implementation Report findings. Personal correspondence. 2005.
- USGS. *Hydraulic Conductivity and Water Quality of the Shallow Aquifer, Palm Beach County, Florida*. Water-Resources Investigations 76-119. April, 1977.

This technical memorandum provides updated information and results from the technical memoranda submitted on May 31, 2005 for the Test Cell Program (Black & Veatch, 2005).

5. HYDROGEOLOGY

The EAA A-1 Reservoir site is located within the Everglades physiographic subdivision of Palm Beach County. The Everglades is generally flat, and the ground surface elevations within the area of the reservoir site are approximately 8 to 10 ft North American Vertical Datum of 1988 (NAVD). Beneath the reservoir site, the geologic formations are grouped into three separate hydrologic units: (1) the shallow unconfined aquifer (surficial aquifer), (2) a lower deep confined aquifer system (Floridan Aquifer System), and (3) a middle unit that forms a confining bed (aquitard) separating these two aquifers. This evaluation focuses on the surficial aquifer.

The surficial aquifer consists of surficial peat and organic soils underlain by the Fort Thompson Formation of Pleistocene age, the Caloosahatchee Marl of Pliocene age, and the upper portions of the Tamiami Formation of Miocene age. The confining unit at the base of the surficial aquifer consists of the lower portions of the Tamiami Formation and the upper portions of the Hawthorn Formation, both of Miocene age.

Several significant hydrogeologic units were identified and confirmed during the Test Cell Program as follows:

5.1 Muck/Peat

The muck layer consists of generally organic deposits occurring at the ground surface. The muck soils can range in consistency from fibrous to granular and are a result of the deposition of decaying plant matter. Regionally, the thickness of these soils ranges from less than one foot to as great as 13 ft. Previous to agricultural and water level management activities in the study area, the thickness of these surficial soil deposits was as great as 17 ft. The muck soils are found to be permeable, with a large moisture storage capacity and a high capillary potential. Site specific information within the study area indicates that the average depth of the muck was found to extend to approximately 1.0 to 2.0 ft, below ground surface (bgs) with an average thickness of approximately 1.4 ft, ranging from 1.1 to 1.7 ft. Agricultural activities have reduced the thickness of the muck layer within the study area.

5.2 Caprock

Underlying the muck layer across much of the reservoir area, there is a solution-riddled calcareous limestone layer referred to as "caprock." The caprock has been considered to be part of the upper Fort Thompson stratigraphic unit, however for purposes of this study the caprock is being considered as a separate stratigraphic unit. Based upon available soil borings and monitoring wells drilled throughout the reservoir site, the caprock has a thickness of approximately 3 to 10 ft (Black & Veatch, 2005; Williams Earth Sciences, 2004; Nodarse, 2002). The caprock and muck layers have been extensively breached by a large network of agricultural canals throughout the EAA.

5.3 Fort Thompson Formation

The sediments that comprise the Fort Thompson Formation are highly variable consisting of unconsolidated, calcareous and fossiliferous quartz sands; well indurated, sandy fossiliferous marine and freshwater limestone; clayey sand; and sandy clays. The top of the Fort Thompson Formation is a hard limestone, which as discussed above is locally identified as caprock. Lower portions of the Fort Thompson Formation consist of interbedded layers of shell, calcareous marine sands (calcilutite), and thin layers of limestone. The sands are moderate brown to white, fine to medium grained, moderately rounded, with intergranular porosity. Pebble to cobble size limestone is present in the sand and shell layers. The limestone is light brown in color, microcrystalline and skeletal with moldic porosity (Scott, 1992). Based on available boring log information, the thickness of the Fort Thompson Formation beneath the reservoir site is approximately 26 ft.

Observations made during the recent test cell program indicate that a significant amount of groundwater seepage occurs within or along the interface of the limestone layers within the Fort Thompson Formation. The limestone layers within the Fort Thompson Formation, including the upper caprock, were reportedly jointed and contained solution cavities and channels. The channels were several inches in diameter and appeared to fully penetrate the limestone layers. The solution channels within the caprock also contained soil including both peat and marl.

5.4 Caloosahatchee Marl

The Caloosahatchee Marl is similar in composition as the Fort Thompson Limestone consisting of sandy marl, clay, silty sand, and shell beds, but generally has a higher quantity of silts and clays. However, the proportions of carbonate and quartz sand vary greatly within this formation. Based on borings drilled during the Test Cell Program, the top of the Caloosahatchee was encountered at a depth of approximately 30 to 40 ft bgs. Available information indicates that this formation thins from a thickness of about 70 ft at Belle Glade to about 7 ft near the Broward County Line.

5.5 Tamiami Formation

The Tamiami Formation consists of sand, clayey sand and poorly consolidated cream to white limestone and greenish-gray clay and marl. The permeability of the Tamiami Formation has been estimated by others to be moderate to low with the upper portions of the aquifer providing fair yields of water (Scott, 1992). It is difficult to differentiate between the Calooshatchee and Tamiami Formation sands based upon soil borings, so it is common to refer to the shelly quartz sand encountered below the Fort Thompson as the Caloosahatchee/Tamiami Formation. For purposes of this seepage evaluation, the Caloosahatchee and the Tamiami are included as separate layers in the groundwater model which is consistent with other studies of the aquifer system in the area (USACE, 2005; SFWMD, USACE, Kimley-Horn, 2004).

The lower portion of the Tamiami Formation and the upper portion of the Hawthorn Formation form the confining unit between the surficial aquifer and the Floridan Aquifer (Scott, 1992). The surficial aquifer extends to an approximate depth of -210 to -220 ft NAVD beneath the area of the reservoir site (Miller, 1987), so this depth was used as the base of the Tamiami Formation. Additional deeper borings are planned as part of Work Order No. 9 (Geotechnical Services) to help determine the depth of Tamiami Formation.

5.6 Hawthorn Group

The Hawthorn Group is generally impermeable consisting of sandy, phosphatic marl, interbedded with clay, shell marl, silt, and sand It forms the confining unit separating the surficial aquifer and the Floridan Aquifer. The deeper confined aquifer of the upper Floridan Aquifer System is composed primarily of limestone belonging to the lower portions of the Hawthorn Group, Tampa, Suwannee, Ocala, and Avon Park Formations. The groundwater model for EAA Reservoir A-1 extends to the top of the Hawthorn Group.

6. MODEL DEVELOPMENT AND METHODOLOGY

The Groundwater Modeling System (GMS) Version 5.1 was chosen to evaluate the seepage from EAA Reservoir A-1. GMS is a proprietary software application developed at Brigham Young University that is capable of expediting the development and analysis of three-dimensional MODFLOW groundwater models. This is the same application that the USACE is using for the Project Implementation Report (PIR).

Two MODFLOW groundwater models were developed for this evaluation. A smaller scale model was developed for the area surrounding the test cells, and a larger scale model was developed for EAA Reservoir A-1. Steady-state conditions were evaulated for both models. The test cell MODFLOW model was used for calibration of the hydraulic conductivities of the aquifer layers by matching model results to measurements taken during the Test Cell Program. The hydraulic conductivity values determined from the test cell MODFLOW model were then used as input to the larger EAA Reservoir A-1 MODFLOW model. The EAA Reservoir A-1 MODFLOW model was used to evaluate the effectiveness of a variety of seepage canal and cutoff wall configurations for different reservoir water levels. The results of the EAA Reservoir A-1 MODFLOW model will be used to aid in the design of the seepage canal, the cutoff wall, and pumps to return seepage back to the reservoir. The results also show impacts to surrounding areas caused by seepage that migrates off-site.

6.1 Test Cell MODFLOW Model Development

The Test Cell Program was conducted from January through May of 2005 within the footprint of the proposed EAA Reservoir A-1 site (see Figure 1 for the location of the test cells in relation to the overall reservoir site). Two 500-foot square test cells were constructed and filled with water to a maximum depth of 12 ft; one test cell was constructed with a cutoff wall beneath the embankment, and one was constructed without a cutoff wall. A seepage canal was constructed around the perimeter of each test cell, and as seepage occurred from the test cells, water was recirculated from the seepage canals back into the test cells maintaining constant water levels in both the cells and the canals. Seventy-two piezometers were installed around the test cells, from which groundwater level measurements were taken during the operation of the test cells. Using the results of the Test Cell Program, a two-dimensional SEEP/W groundwater seepage model was developed and calibrated. For a more detailed description of the Test Cell Program and two-dimensional seepage modeling, a number of technical memoranda were recently submitted to the District (Black & Veatch, 2005).

Parallel to the two-dimensional SEEP/W seepage modeling of the test cells, a three-dimensional MODFLOW model was also developed to determine the vertical and horizontal hydraulic conductivity parameters for each of the aquifer layers underlying the site by matching model results to field measurements. The hydraulic conductivity values were varied within the model until agreement was reached between the model results and the following: (1) the groundwater levels measured in 65 piezometers installed around the test cells on 4/23/05 when equilibrium conditions were achieved for both test cells, (2) the water levels maintained in both test cells and test cell seepage canals on 4/23/05, and (3) the pumping rates from the seepage canals to the test cells required to maintain these constant water levels on 4/23/05.

The test cell MODFLOW model covers an area that is approximately 5.1 miles from east to west by approximately 4.2 miles from north to south. The model grid was aligned on a north-south and east-west pattern, since the general direction of groundwater flow direction is from north to south. The boundaries of the model were chosen significantly far enough away from the test cells to have no impact on the results obtained near the test cells and were assigned constant heads of 6.45 ft NAVD based on water levels measured during testing. The model was discretized with grid cells varying from 20 ft square in the vicinity of the test cells to 500 ft square near the boundaries of the model.

Vertically, the test cell model was divided into 4 aquifer layers as follows:

- The surficial muck/peat layer of between 1 and 2 ft thick was removed at the test cell site for reasons described in previous technical memoranda (Black & Veatch, 2005). Therefore, the muck/peat layer was not included in the model of the test cells.
- Layer 1. Caprock. Top elevation 8 ft NAVD. Bottom elevation 4 ft NAVD.
- Layer 2. Fort Thompson Formation. Top elevation 4 ft NAVD. Bottom elevation -16 ft NAVD.
- Layer 3. Caloosahatchee Marl. Top elevation -16 ft NAVD. Bottom elevation -60 ft NAVD.
- Layer 4. Tamiami Formation. Top elevation -60 ft NAVD. Bottom elevation -210 ft NAVD.

- The Hawthorn Formation underlying the surficial aquifer was not included in the model. It was assumed that the top of the Hawthorn Formation acts as a confining layer and restricts vertical movement of groundwater.

The elevations for the interfaces between the aquifer layers were determined from borings at the test cell site. These borings did not extend to the bottom of the Tamiami Formation. An elevation of -210 ft was obtained from a USGS map of the bottom of the surficial aquifer system (Miller, 1987).

Two nests of three piezometers were installed midway along all four sides of each test cell in the bench between the embankments and the seepage canals. One nest of piezometers was installed near the downstream toe of the embankment, and one nest was installed near the seepage canal. Each nest of piezometers consisted of a shallow piezometer, a middle piezometer, and a deep piezometer. The shallow piezometers were screened in the Fort Thompson Formation from a depth of approximately 6 to 16 ft NAVD. The middle piezometers were screened in the Caloosahatchee Formation from a depth of approximately 32 to 52 ft NAVD. The deep piezometers were screened from a depth of approximately 72 to 92 ft NAVD in the Tamiami Formation. This configuration allowed for measurement of groundwater levels in each of the formations that could be used to determine hydraulic conductivity values for the layers modeled.

The MODFLOW river package was used to simulate the known primary and secondary agricultural canals in close proximity to the test cells. The elevations of these agricultural canals were set to a constant elevation of 6.45 ft NAVD based on background measurements during the test on 4/23/05. The canal conductance, which governs the interaction of the canals with the aquifer, was set equal to 100 ft^2/ft/day assuming a sediment thickness of 1 foot and a sediment conductivity of 1 ft/day based on values from previous and on-going studies.

The seepage canals surrounding each test cell were simulated as constant heads of 6.24 and 6.21 ft NAVD in the model to correspond to the levels the canals achieved on 4/23/05. The test cells were set at constant heads of 20 ft and 20.18 ft NAVD to represent water depths of approximately 12 ft in each cell on 4/23/05. MODFLOW's horizontal flow barrier package was used to simulate the 24 foot deep cutoff wall constructed for one of the test cells. A very low permeability was assigned to the cutoff wall assuming essentially no flow could pass through the wall.

6.2 EAA Reservoir A-1 MODFLOW Model Development

The EAA Reservoir A-1 MODFLOW model covers an area from the Miami to Hillsboro Canals from west to east (approximately 22 miles) and from the Bolles/Cross to I-75 Canals from north to south (approximately 33 miles) as shown on Figure 4.

The model grid was setup on a north-south and east-west pattern, since the general direction of groundwater flow direction is from north to south. The boundaries of the model were chosen significantly far enough away from the EAA Reservoir A-1 site to have very little if any impact on the seepage results obtained for the reservoir. The boundaries were assigned constant heads that varied from 8.85 ft NAVD in the north to 8.6 ft NAVD in the south, providing a slight regional groundwater gradient across the modeled area. The model was discretized with grid cells varying in size from 200 ft by 200 ft in the vicinity of the reservoir to approximately 4200 ft by 4200 ft near the boundaries of the model, with a total of approximately 470,000 cells.

Vertically, the reservoir model was divided into the following five aquifer layers as shown on Figure 5:

- Layer 1. Muck/peat. Elevation range from 9 to 6 ft NAVD
- Layer 2. Caprock. Elevation range from 6 ft to 1 ft NAVD
- Layer 3. Fort Thompson Formation. Elevation range from 1 ft to -25 ft NAVD
- Layer 4. Caloosahatchee Marl. Elevation range from -25 ft to -60 ft NAVD
- Layer 5. Tamiami Formation. Elevation range from -60 ft to -210 ft NAVD
- The Hawthorn Formation underlying the surficial aquifer was not included in the model. It was assumed that the top of the Hawthorn Formation acts as a confining layer and restricts vertical movement of groundwater

The elevations for the interfaces between the aquifer layers were determined from approximately 150 borings drilled by Williams Earth Sciences (2004) and Nodarse & Associates (2002) across the reservoir site, and since these borings cover a much larger area, the elevations are slightly different from the localized area near the test cells. These borings did not extend to the bottom of the Tamiami Formation. An elevation of -210 ft was obtained from a USGS map of the bottom of the surficial aquifer system (Miller, 1987). Several deep borings to define the bottom of the Tamiami Formation and approximately 130 other borings are planned throughout the reservoir site as part of Work Order No. 9 that will provide additional characterization of the stratigraphy of the aquifer. The deep borings may also provide information concerning the interface between the Caloosahatchee and Tamiami Formations.

The MODFLOW river package was used to simulate the major canals within the modeled area such as the North New River Canal, the L-5 and L-6 canals, and the STA 3/4 Supply Canal. The simulated water elevations of these major canals ranged from approximately 8.6 to 11.1 ft NAVD corresponding to water level readings obtained by the USACE on 4/27/05. The canal conductance, which governs the interaction of the canals with the aquifer, was set equal to 100 ft^2/ft/day assuming a sediment thickness of 1 foot and a sediment conductivity of 1 ft/day.

The seepage canal and cutoff wall were simulated along the east, north, and part of the west sides of the reservoir as shown on Figure 6. The seepage canal was simulated using the MODFLOW river package with the operating water level of the seepage canal set at 6.5 ft NAVD. The seepage canal conductance was set equal to 100 ft^2/ft/day assuming a sediment thickness of 1 foot and a sediment hydraulic conductivity of 1 ft/day. Two depths (bgs) of 10 ft and 20 ft were evaluated to determine the effectiveness of the canal at controlling seepage from the reservoir. The cutoff wall was simulated using the MODFLOW horizontal flow barrier package with a very low permeability. Two cutoff wall depths (bgs) of 34 ft (bottom of the Fort Thompson Formation) and 69 ft (bottom of the Caloosahatchee Marl Formation) were evaluated to determine the effectiveness of the cutoff wall at controlling seepage from the reservoir. The exact depths of the cutoff wall will be refined as the additional borings are drilled in Work Order No. 9. Along the south and southwest side of the reservoir, the proposed embankment may be built over top of an existing seepage canal for the STA 3/4 Supply Canal. If so, it has been proposed that this seepage canal be filled with impermeable material that would serve as a shallow cutoff wall. Therefore, a shallow 10-foot cutoff wall was simulated along the south and southwest side of the reservoir.

Several water levels were evaluated for the reservoir to develop a rating curve for the seepage rate. Obviously, seepage will increase with reservoir water depth. MODFLOW model runs were made for reservoir water depths of 1, 3, 6, 12, 15, and 18 ft.

7. MODEL RESULTS

7.1 Test Cell MODFLOW Model Results

As mentioned previously, the objective of the three-dimensional MODFLOW model of the test cells was for calibration to the data collected during of the Test Cell Program to determine horizontal and vertical hydraulic conductivity values for each of the aquifer layers that could subsequently be used as input for the larger MODFLOW model of EAA Reservoir A-1. The results of this calibration provided a match for the seepage rates measured from both test cells and very good agreement between measured and calculated groundwater heads for the 65 piezometers included in the analysis. The results of the calibration are given in Tables 1 and 2.

The horizontal (K_h) and vertical (K_v) hydraulic conductivity values used to obtain this calibration are given in Table 3.

The calibration to the results of the Test Cell Program was very sensitive to the K_v values for the caprock, Fort Thompson, and Caloosahatchee layers. The ratios of K_v/K_h are low compared to published ratios of hydraulic conductivity which are usually based on aquifer tests which do not exhibit the same effect on the aquifer as did the test cells. These ratios of K_v/K_h were necessary to calibrate to the test cell results for both this MODFLOW calibration and for an independent calibration using the two-dimensional SEEP/W program. In addition to the differences between using test cells instead of other methods to determine hydraulic conductivity, another reason for these K_v/K_h ratios could be attributed to movement of water along the interfaces between layers with significantly different characteristics (such as between thin layers of limestone and the surrounding formation). The K values given in Table 3 represent average hydraulic conductivities for the entire layer including any thin seams of high (or low) permeability that may be included within these layers.

Because of the inherent differences between the three-dimensional MODFLOW model and the two-dimensional SEEP/W model, the hydraulic conductivity values determined from each of these models are slightly different as shown in the Reservoir Seepage Analysis Technical Memorandum (Black & Veatch, Molyneux, 2005). Although the values are slightly different, both sets of hydraulic conductivity values produce very comparable seepage results when applied to the EAA Reservoir A-1 model, as described below.

7.2 EAA Reservoir A-1 MODFLOW Model Results

Once the EAA Reservoir A-1 MODFLOW model was developed, a large number of model runs were performed to determine the sensitivity of the model to the input parameters. Appendix 6-3 lists the findings of the sensitivity analysis. The major finding was that, similar to the findings of the test cell model, the reservoir model is most sensitive to the vertical hydraulic conductivities of the upper aquifer layers. The sensitivity analysis also showed that the reservoir model predicts similar seepage rates for all three sets of hydraulic conductivity values determined by (1) the MODFLOW calibration to the test cell data, (2) the SEEP/W calibration to the test cell data, and (3) the values the USACE is currently using for the PIR. However, by using the Corps' hydraulic conductivity values for the muck layer, the seepage was dramatically reduced. Since the muck layer is absent wherever there is a canal, hydraulic conductivity values from the Corps were increased for this evaluation as shown in Table 3. The sensitivity analysis also showed that although there are far too many farm canals to add to the model, the addition of just a few farm canals had a significant effect on groundwater levels. This supports the reported findings of the regional MIKE SHE hydrologic modeling being performed by others that existing groundwater levels in the EAA are heavily influenced by the operation of the farms canals (SFWMD, USACE, Kimley-Horn, 2004).

Following the sensitivity analysis, the EAA Reservoir A-1 model was used to evaluate a variety of alternatives for seepage control. Table 4 recaps the model parameters that were held constant during this evaluation, and Table 5 shows the model parameters that were varied to determine the effectiveness of various seepage control alternatives. The hydraulic conductivity values determined from the calibration of the test cell MODFLOW model were applied to the larger-scale MODFLOW model of EAA Reservoir A-1.

There were a total of 24 permutations of the variables shown in Table 5, and the results of each permutation are given in Table 6. Based on these model results, rating curves were developed for the total rate of seepage with relation to reservoir water depth as shown in Appendix 6-4. The following equations were established for seepage rates ($Q_{seepage}$ in cfs):

$Q_{seepage} = 25.135 \times d_{reservoir}$ for 34-ft bgs cutoff wall and 10-ft bgs seepage canal
$Q_{seepage} = 25.951 \times d_{reservoir}$ for 34-ft bgs cutoff wall and 20-ft bgs seepage canal
$Q_{seepage} = 15.418 \times d_{reservoir}$ for 69-ft bgs cutoff wall and 10-ft bgs seepage canal
$Q_{seepage} = 15.622 \times d_{reservoir}$ for 69-ft bgs cutoff wall and 20-ft bgs seepage canal

Rating curves were also developed to estimate the amount of seepage that will be collected by the seepage canal (see Appendix 6-4). These rating curves will be used as input for the overall water balance model of the reservoir being conducted under another task to simulate the filling and emptying of the reservoir. The curves will also be used for the design of pumps to return seepage back to the reservoir.

Table 7 shows the change in flow caused by the reservoir. With the exception of the seepage from the reservoir and the elimination of the farms within the reservoir footprint, all flow changes are negative, meaning that the seepage and the elimination of the farms within the reservoir footprint will cause the canals and surrounding areas to take on more water.

As shown in Table 7, the total seepage from the reservoir is between 92 cfs and 314 cfs when the reservoir has a water depth between 6 and 12 ft, depending on the depths of the seepage canal and cutoff wall. It should be noted that these MODFLOW analyses assume steady state conditions where the reservoir is assumed to be held at these water levels indefinitely. In reality, the reservoir water levels will be highly variable, so these seepage rates represent the maximum seepage that the reservoir would experience under the assumed conditions.

The seepage canal collects between 60 and 80 percent of the total seepage from the reservoir when the reservoir water depth is between 6 and 12 ft. For example, when the reservoir has 12 ft of water with a 34-ft bgs cutoff wall depth and a 10-ft bgs seepage canal depth, the model shows the seepage canal will collect 64 percent of the total seepage from the reservoir. The remaining 36 percent of the seepage will migrate off-site to the major canals and the surrounding areas such as the farm lands and STA 3/4. The model shows that the North New River Canal and the STA 3/4 Supply Canal collect a significant amount of seepage that escapes past the seepage canal. Most of the remaining seepage migrates primarily to STA 3/4, the farm lands to the northwest of the reservoir site, and the Holey Land. A small amount of seepage migrates to the farm lands to the east of the North New River and Compartment B. The model shows that no seepage migrates to STA 2, WCA 2, WCA 3, or the boundaries of the model for any of the scenarios evaluated.

An estimate of the total unrecoverable seepage could be made from Table 7 by summing the first three columns as follows:

Unrecoverable seepage = Total seepage +
(-seepage collected by seepage canal) +
(-seepage collected by NNR)

This assumes that any seepage that is collected by the North New River will be pumped back into the reservoir. For the scenario with 12 ft of water in the reservoir, a 34-ft cutoff wall, and a 10-ft seepage canal, this would give 70.3 cfs of unrecoverable seepage, or 23 percent of the total seepage. This is only an estimate of the unrecoverable seepage since some of the flow collected by the seepage canal is not from seepage but from background water on the opposite side of the canal (for example, some water is drawn into the seepage canal from the North New River). It is also possible that the seepage that migrates to the farm lands could be pumped back to the North New River and returned to the reservoir. A significant amount of seepage enters the STA 3/4 Supply Canal which may not be returned to the reservoir but distributed to STA 3/4.

7.3 Seepage Effects on Areas Surrounding EAA Reservoir A-1

The areas on each side of the reservoir site have different conditions and constraints. The seepage caused by a reservoir water depth of 12 ft with a cutoff wall 34 ft bgs and a seepage canal 10 ft bgs was analyzed in more detail to provide a quantitative and qualitative assessment of the impacts seepage will have on these areas.

7.3.1 Farm Lands

To the north and northwest of the reservoir and to the east of the North New River, the water levels in farm lands are currently controlled by a large network of shallow canals. To irrigate the fields, water is obtained from the larger canals and allowed to flow into the fields. During wet conditions, water is pumped out of the fields through the canals and into the major SFWMD canals such as the North New River. The maximum amount of pumping is controlled by regulatory permits. The SFWMD canals are maintained at levels which are several ft higher than the farm canals, so the farm canals are currently inducing seepage from the SFWMD canals (SFWMD, USACE, Kimley-Horn, 2004).

The most appropriate method for simulating existing conditions in the region is to account for the farm canals and calibrate the pumping rates in these canals until the operating water levels are achieved. This effort is being performed by A.D.A. Engineers using the regional MIKE-SHE model of the EAA. The limitations of MODFLOW also make it nearly impossible to account for all of the individual farm canals in the model. Therefore, to simulate existing conditions in the farm lands surrounding EAA Reservoir A-1, a constant head of 6.1 ft NAVD was applied to the top muck layer in the MODFLOW model across the entire area being farmed to represent the average groundwater levels maintained in the farm lands.

Once the reservoir is operational and a portion of the seepage begins to migrate to the farm lands, the farm canals could be operated in several ways in the future. The farm lands could be maintained at the same water levels as today by pumping the farm canals at slightly higher rates to offset the additional water entering these areas from seepage, assuming the permitted drainage rates and the conveyance capacity are not exceeded. Or, the farm canals might be pumped at the same rates as today, in which case the water levels in the farm lands would be allowed to rise. Since seepage will most likely occur during both dry and wet periods of the year, the additional water from seepage could provide a benefit for the farms during drier portions of the year.

With 12 ft of water in the reservoir, a cutoff wall 34 ft bgs, and a seepage canal 10 ft bgs, the model results indicate that approximately 14 cfs (or 6,300 gallons per minute (gpm)) will bypass the seepage canal and migrate to the farm lands to the northwest of the reservoir. The perimeter of the reservoir facing the farms to the northwest is approximately 5.7 miles. The model results indicate seepage is relatively uniform across this boundary, so the seepage will be approximately 1,100 gpm per mile of embankment.

To put this seepage rate into perspective, calculations were made to determine the amount of additional pumping that would need to occur compared to the amount of drainage that is permitted. A strip of farm land of 2,000 ft wide along one mile of the northwest side of the reservoir was considered; the total area for this strip of farm land is 242 acres. If the average permitted drainage rate from the 242 acres is 1.0 inch per day (Stewart, 2002), then the maximum that could be drained from this land is 878,460 ft^3 per day. The seepage rate of 1,100 gpm per mile of embankment equals approximately 211,750 ft^3 per day, or 24 percent of the total permitted drainage rate. Therefore, the farm canals within 2,000 ft of the seepage canal to the northwest of the reservoir that are currently operated at a maximum of 76 percent of the 1.0 inch per day (or 0.76 inches per day) during the wettest periods of the year should be able to drain all of the additional water from seepage under their current permit limitations. This is assuming the pumps and associated conveyance facilities are sized to pump the full permitted amount of 1.0 inch per day. This also represents a rare condition of 12 ft of water in the reservoir coinciding with the wettest period of the year. In most cases, the reservoir will be filling during the wettest period of the year.

There will be times when the water level in the reservoir gets drawn down significantly to meet irrigation and environmental water demands (Black & Veatch, Frias and Henson, 2005). At 6 ft, seepage from the reservoir that migrates to the farms to the northwest for this scenario is approximately 9 cfs (or 4,040 gpm), or about 709 gpm per mile of embankment. Assuming farm lands within 2000 ft of the reservoir have a permitted pumping rate of 1.0 inch per day, this represents 16 percent of the total permitted pumping rate.

According to the model, the seepage that migrates to the farm lands on the east side of the North New River will only be 1 or 2 cfs (450 to 900 gpm) across a boundary of nearly five miles. This is a maximum of 180 gpm per mile of embankment. Again, for a strip of farm land 2,000 ft wide and assuming a permitted pumping rate of 1.0 inch per day, this amount of seepage is approximately 4 percent of the total permitted pumping rate and will only occur for the occasions when the reservoir is relatively full.

With this information, it seems likely that the farm canals within several thousand ft of the reservoir should be able to manage the additional water from seepage during the wet periods when water is being pumped out of the fields, and the farm lands will benefit from the seepage during dry seasons.

7.3.2 US Highway 27

US Highway 27 is located along the east side of the reservoir site between the North New River Canal and the proposed seepage canal for EAA Reservoir A-1. Increases in groundwater levels beneath the highway may or may not be acceptable depending on what the existing groundwater levels beneath the highway are at the time that seepage occurs. If the groundwater levels remain beneath the base of the highway, then no adverse impacts should occur.

7.3.3 STA 3/4 and the Holey Land

STA 3/4 is designed to treat about 400,000 acre-ft of runoff and about 250,000 acre-ft of releases from Lake Okeechobee each year. Averaged over the entire year, this is equivalent to approximately 829 cfs. An additional 8 to 13 cfs from seepage when the reservoir depth is between 6 and 12 ft would only be about 1 percent of the total capacity of STA 3/4.

The Florida Fish and Wildlife Conservation Commission (FFWCC) operates the Holey Land as a wildlife management area, and the SFWMD regulates water levels within an acceptable range for the area. From May 15 through October 31, the levels are allowed to increase from approximately 9.1 ft NAVD to 10.6 ft NAVD, and from November 1 through May 14, the levels are regulated to decline from 10.6 ft to 9.1 ft NAVD. Water levels are regulated within this range using the structures along the Miami Canal. The model results indicate that seepage from EAA Reservoir A-1 will increase flow to this area at a rate of between 4 and 6.7 cfs when the reservoir level is between 6 and 12 ft deep. This will occur along a stretch of approximately 2.6 miles of embankment.

Under an extreme condition with the reservoir maintaining a depth of 12 ft indefinitely with no seepage canal and a shallow cutoff wall 10 ft deep along the south and southwest sides of the reservoir, Figure 7 shows how the model predicts groundwater levels will rise in the Holey Land and STA 3/4 due to seepage. Under this condition, the groundwater levels would rise by 0.5 foot at a distance of approximately 2 miles into the Holey Land and 2.7 miles into STA 3/4. Groundwater levels will rise by 1.5 ft at a distance of 0.2 mile into the Holey Land and 0.4 mile into STA 3/4. However, it is expected that these levels could be controlled by proper operation of these areas, such as feeding less water from the Supply Canal during times when seepage is high, or by releasing more water at the downstream end of these areas. This will be addressed in the final operations manual. Even without the ability to control the amount of flow entering STA

3/4, the increases in water levels shown by Figure 7 may stay within the operating range for which it was designed.

8. CONCLUSIONS

This EAA Reservoir A-1 seepage evaluation provides information regarding the quantity of seepage that can be expected from the reservoir, the amount of seepage that can be collected by a perimeter seepage canal and returned to the reservoir, and the amount of seepage that will migrate off-site and affect surrounding areas. This evaluation represents an extreme scenario assuming the reservoir remains full indefinitely, allowing the seepage to establish equilibrium with surrounding areas and the groundwater to achieve maximum levels.

This seepage evaluation will continue to evolve during the design of EAA Reservoir A-1. The results given in this memorandum will assist in the comparison of the different alternatives for seepage control. Once the alternatives are narrowed to the preferred alternatives, additional seepage modeling will be performed to evaluate the most appropriate location and depth of the cutoff wall and seepage canal, and the effects of seepage on the surrounding areas will be evaluated in greater detail.

9. ADDENDUM

Since the first issue of this technical memorandum, addition model runs were requested by various members of the design and review teams associated with this project. The model runs included (1) no cutoff wall around EAA Reservoir A-1, and (2) a shallow 10-ft deep cutoff wall along the west boundary of the reservoir where Reservoir A-2 will be constructed in the future.

With no cutoff wall around the perimeter of EAA Reservoir A-1, the total seepage from the reservoir will increase by approximately 30 percent over the alternative with a 34-ft deep cutoff wall around the west, north, and east sides and a 10-ft deep cutoff wall along the south side.

The shallow 10-ft deep cutoff wall along the west side was evaluated to determine if there could be construction cost savings in exchange for more seepage and higher pumping costs over the life of the project. Seepage increased by approximately 2.5 percent over the alternative with a 34-ft deep cutoff wall along the west boundary. According to the model, most of this additional seepage will be collected by a seepage canal along the west boundary with only a slight amount (1 cfs or less) migrating past the seepage canal to the farm areas to the west. Additional modeling is being performed using the two-dimensional SEEP/W computer program to determine how much seepage pressures will increase with a shallow cutoff wall along the west side of EAA Reservoir A-1. If seepage pressures become too high, the stability of the embankment could be compromised, and a shallow cutoff wall will be eliminated from further consideration.

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TABLES

Table 1 Calibration of MODFLOW Model to Seepage Rates

Measured during Test Cell Program on 4/23/05			
	Measured	Calculated by Model	Difference
Test Cell #1 Seepage Rate	3,900 gpm	3,845 gpm	-1.40 %
Test Cell #2 Seepage Rate	1,900 gpm	1,895 gpm	-0.25 %

Table 2 Calibration of MODFLOW Model to Groundwater Levels

Measured during Test Cell Program on 4/23/05			
Piezometers	Measured Heads (ft NAVD)	Computed Heads (ft NAVD)	Residual (ft NAVD)
PZ1/2BGNA	6.31	6.70	0.39
PZ1/2BGNB	6.57	6.80	0.23
PZ1/2BGNC	6.64	6.86	0.22
PZ1BGSA	6.28	6.60	0.32
PZ1BGSB	6.28	6.62	0.34
PZ1BGSC	6.35	6.63	0.28
PZ1E1	10.31	10.86	0.55
PZ1E2A	8.76	9.30	0.54
PZ1E2B	7.58	8.29	0.71
PZ1E2C	6.86	7.94	1.08
PZ1E3A	7.46	7.46	0.00
PZ1E3B	6.99	7.73	0.74
PZ1E3C	6.86	7.64	0.78
PZ1N1	9.51	10.83	1.32
PZ1N2A	8.4	9.07	0.67
PZ1N2B	7.42	8.21	0.79
PZ1N2C	6.88	7.89	1.01
PZ1N3A	7.26	7.31	0.05
PZ1N3B	6.93	7.69	0.76
PZ1N3C	6.75	7.61	0.86
PZ1S1	11.22	11.01	-0.21
PZ1S2A	8.5	9.40	0.90
PZ1S2B	8.24	8.30	0.06
PZ1S2C	7	7.94	0.94
PZ1S3A	7.35	7.45	0.10
PZ1S3B	7.17	7.73	0.56

Measured during Test Cell Program on 4/23/05			
Piezometers	Measured Heads (ft NAVD)	Computed Heads (ft NAVD)	Residual (ft NAVD)
PZ1S3C	6.83	7.63	0.80
PZ1W1	9	10.77	1.77
PZ1W2A	8.76	9.24	0.48
PZ1W2B	7.58	8.26	0.68
PZ1W2C	6.86	7.91	1.05
PZ1W3A	7.46	7.41	-0.05
PZ1W3B	6.99	7.70	0.71
PZ1W3C	6.86	7.61	0.75
PZ21E	7.73	9.29	1.56
PZ21S1	7.67	7.11	-0.56
PZ2BGNA	6.24	6.55	0.31
PZ2BGNB	6.31	6.58	0.27
PZ2BGNC	6.36	6.61	0.25
PZ2E2A	7.55	6.94	-0.61
PZ2E2B	7.29	7.99	0.70
PZ2E2C	6.81	7.79	0.98
PZ2E3A	6.95	6.55	-0.40
PZ2E3B	6.96	7.45	0.49
PZ2E3C	6.74	7.47	0.73
PZ2N1	7.72	8.17	0.45
PZ2N2A	7.18	6.90	-0.28
PZ2N2B	7.18	8.02	0.84
PZ2N2C	6.74	7.80	1.06
PZ2N3A	6.69	6.50	-0.19
PZ2N3B	6.92	7.48	0.56
PZ2N3C	6.73	7.50	0.77
PZ2S2A	7.04	6.93	-0.11
PZ2S2B	7.16	7.92	0.76
PZ2S2C	6.83	7.76	0.93
PZ2S3A	6.56	6.49	-0.07
PZ2S3B	6.77	7.39	0.62
PZ2S3C	6.72	7.43	0.71
PZ2W1	7.78	7.11	-0.67
PZ2W2A	7.34	6.93	-0.41
PZ2W2B	7.06	7.95	0.89
PZ2W2C	6.78	7.78	1.00
PZ2W3A	6.68	6.50	-0.18
PZ2W3B	6.87	7.41	0.54
PZ2W3C	6.66	7.47	0.81

Measured during Test Cell Program on 4/23/05			
Piezometers	Measured Heads (ft NAVD)	Computed Heads (ft NAVD)	Residual (ft NAVD)
		Average difference	**0.49 feet**

Table 3 Hydraulic Conductivity Values Determined with MODFLOW

Layer	K_h (ft/day)	K_v (ft/day)
Muck/peat [1]	100	100
Caprock	500	1.1
Fort Thompson	400	10
Caloosahatchee	400	8
Tamiami [2]	36	18

[1] Muck was removed from test cells, so calibration to the K values for the muck was not possible. Initially used values determined by the USACE through laboratory/field testing of the muck which were Kh = 40 ft/day and Kv = 9 ft/day (USACE, 2005), but increased these values to account for the significant area where muck does not exist (e.g., where the canals are located).
[2] The seepage from the test cells did not affect deep portions of the surficial aquifer, so calibration to the K values for the Tamiami was not possible. Used the USACE's values determined from laboratory/field testing.

Table 4 Groundwater Model Parameters Held Constant

Parameter	**Value**
Ground Elevation	9 ft NAVD
Bottom of Muck/Peat	6 ft NAVD
Bottom of Caprock	1 ft NAVD
Bottom of Fort Thompson	-25 ft NAVD
Bottom of Caloosahatchee	-60 ft NAVD
Bottom of Tamiami	-210 ft NAVD
K_h:K_v Muck	100:100 ft/day
K_h:K_v Caprock	500:1.1 ft/day
K_h:K_v Fort Thompson	400:10 ft/day
K_h:K_v Caloosahatchee	400:8 ft/day
K_h:K_v Tamiami	36:18 ft/day
Constant Head Boundary Conditions	8.85 ft NAVD at Bolles and Cross Canals 8.6 ft NAVD at I-75 Canal
Canal Conductance	100 ft^2/ft/day
Major Canal Water Levels	Ranging from 8.85 ft NAVD for NNR to 11.1 ft NAVD for Supply Canal
Farm Canal Water Levels	6.1 ft NAVD

STA 3/4, STA 2, Compartment B Levels	10.6 ft NAVD
Holey Land Water Level	10.1 ft NAVD
WCA 2 Water Level	9.6 ft NAVD
WCA 3 Water Level	8.1 ft NAVD
Seepage Canal Water Level	6.5 ft NAVD
Seepage Canal Location	East, North, and Northwest Sides of Reservoir
Deep Cutoff Wall Location	East, North, and Northwest Sides of Reservoir
Shallow Cutoff Wall Location	South and Southwest Sides of Reservoir

Table 5 Groundwater Model Parameters Varied

Parameter	**Values**
Seepage Canal Depth	10 ft bgs and 20 ft bgs
Deep Cutoff Wall Depth	34 ft bgs* and 69 ft bgs**
Reservoir Water Depth	1, 3, 6, 12, 15, and 18 ft above ground surface
*bottom of Fort Thompson Formation; **bottom of Caloosahatchee Formation	

Table 6 Reservoir A-1 MODFLOW Model Results*

All flows are given in units of cubic feet per second (cfs)
Positive (+) flow indicates water is added to the groundwater system
Negative (-) flow indicates water is removed from the groundwater system

Reservoir Depth (ft), Cutoff Wall Depth (ft), Seepage Canal Depth (ft)	Total Reservoir Seepage (cfs)	Net Flow for Seepage Canal (cfs)	Net Flow for NNR (cfs)	Net Flow for STA 3/4 Supply Canal (cfs)	Net Flow for STA 3/4 (cfs)	Net Flow for NW Farms (cfs)	Net Flow for NE Farms (cfs)	Net Flow for Compartment B (cfs) (modeled as an STA)	Net Flow for Holey Land (cfs)
Baseline - (prereservoir)	*-64***	-	*46*	*73*	*18*	*-73*	*-199*	*62*	*2.2*
1, 34, 10	41	-64	41	47	15	-78	-199	62	0.5
1, 34, 20	44	-72	44	48	15	-77	-199	62	0.5
1, 69, 10	15	-45	46	47	15	-76	-199	62	0.5
1, 69, 20	16	-49	48	47	15	-76	-199	62	0.5
3, 34, 10	89	-88	35	34	13	-80	-199	62	-0.5
3, 34, 20	93	-98	39	35	13	-79	-199	62	-0.5
3, 69, 10	46	-56	43	34	13	-77	-199	62	-0.5
3, 69, 20	47	-61	45	34	13	-77	-199	62	-0.4
6, 34, 10	160	-124	26	15	10	-82	-200	61	-1.8
6, 34, 20	167	-137	31	15	10	-81	-199	61	-1.8
6, 69, 10	92	-72	38	15	10	-79	-199	62	-1.8
6, 69, 20	94	-78	42	15	10	-78	-199	62	-1.8
12, 34, 10	303	-195	8.3	-24	5.1	-87	-201	61	-4.5
12, 34, 20	314	-216	16	-24	5.1	-85	-200	61	-4.5
12, 69, 10	185	-105	29	-24	5.1	-82	-200	61	-4.5
12, 69, 20	188	-114	34	-24	5.1	-80	-199	61	-4.5

All flows are given in units of cubic feet per second (cfs) Positive (+) flow indicates water is added to the groundwater system Negative (-) flow indicates water is removed from the groundwater system									
Reservoir Depth (ft), Cutoff Wall Depth (ft), Seepage Canal Depth (ft)	Total Reservoir Seepage (cfs)	Net Flow for Seepage Canal (cfs)	Net Flow for NNR (cfs)	Net Flow for STA 3/4 Supply Canal (cfs)	Net Flow for STA 3/4 (cfs)	Net Flow for NW Farms (cfs)	Net Flow for NE Farms (cfs)	Net Flow for Compartment B (cfs) (modeled as an STA)	Net Flow for Holey Land (cfs)
15, 34, 10	375	-230	-0.7	-44	2.4	-90	-201	60	-5.9
15, 34, 20	387	-256	8.4	-43	2.5	-87	-201	61	-5.9
15, 69, 10	231	-121	25	-44	2.4	-83	-200	61	-5.9
15, 69, 20	234	-132	30	-43	2.4	-81	-200	61	-5.8
18, 34, 10	447	-266	-9.7	-63	-0.2	-93	-202	60	-7.3
18, 34, 20	460	-295	0.8	-63	-0.2	-89	-201	60	-7.2
18, 69, 10	278	-138	20	-63	-0.3	-84	-200	61	-7.2
18, 69, 20	281	-150	26	-63	-0.3	-83	-200	61	-7.2
* Model showed no impact on STA 2, WCA 2, or WCA 3. Model showed very little impact to Compartment B or farms to the east. ** The farms located in the footprint of the reservoir currently remove 64 cfs from the groundwater system.									

Table 7 Impact of Reservoir A-1 on Groundwater Flow*

All flows are given in units of cubic feet per second (cfs) and were determined by taking the difference between the flows given in Table 7-6 for each of the scenarios and baseline conditions Positive (+) flow indicates water added to the groundwater system in excess of existing conditions Negative (-) flow indicates the additional water that is withdrawn from the groundwater system in excess of existing conditions										
Reservoir Depth (ft), Cutoff Wall Depth (ft), Seepage Canal Depth (ft)	Total Reservoir Seepage (cfs)	Net Flow for Seepage Canal (cfs)	Net Flow for NNR (cfs)	Net Flow for STA 3/4 Supply Canal (cfs)	Net Flow for STA 3/4 (cfs)	Net Flow for NW Farms (cfs)	Net Flow for NE Farms (cfs)	Net Flow for Compartment B (cfs) (modeled as an STA)	Net Flow for Holey Land (cfs)	Reservoir farms eliminated (cfs)
1, 34, 10	41	-64	-5	-26	-3	-5	0	0	-1.7	64
1, 34, 20	44	-72	-2	-25	-3	-4	0	0	-1.7	64
1, 69, 10	15	-45	0	-26	-3	-3	0	0	-1.7	64
1, 69, 20	16	-49	2	-26	-3	-3	0	0	-1.7	64
3, 34, 10	89	-88	-11	-39	-5	-7	0	0	-2.7	64
3, 34, 20	93	-98	-7	-38	-5	-6	0	0	-2.7	64
3, 69, 10	46	-56	-3	-39	-5	-4	0	0	-2.7	64

All flows are given in units of cubic feet per second (cfs) and were determined by taking the difference between the flows given in Table 7-6 for each of the scenarios and baseline conditions
Positive (+) flow indicates water added to the groundwater system in excess of existing conditions
Negative (-) flow indicates the additional water that is withdrawn from the groundwater system in excess of existing conditions

Reservoir Depth (ft), Cutoff Wall Depth (ft), Seepage Canal Depth (ft)	Total Reservoir Seepage (cfs)	Net Flow for Seepage Canal (cfs)	Net Flow for NNR (cfs)	Net Flow for STA 3/4 Supply Canal (cfs)	Net Flow for STA 3/4 (cfs)	Net Flow for NW Farms (cfs)	Net Flow for NE Farms (cfs)	Net Flow for Compartment B (cfs) (modeled as an STA)	Net Flow for Holey Land (cfs)	Reservoir farms eliminated (cfs)
3, 69, 20	47	-61	-1	-39	-5	-4	0	0	-2.6	64
6, 34, 10	160	-124	-20	-58	-8	-9	-1	-1	-4	64
6, 34, 20	167	-137	-15	-58	-8	-8	0	-1	-4	64
6, 69, 10	92	-72	-8	-58	-8	-6	0	0	-4	64
6, 69, 20	94	-78	-4	-58	-8	-5	0	0	-4	64
12, 34, 10	303	-195	-37.7	-97	-12.9	-14	-2	-1	-6.7	64
12, 34, 20	314	-216	-30	-97	-12.9	-12	-1	-1	-6.7	64
12, 69, 10	185	-105	-17	-97	-12.9	-9	-1	-1	-6.7	64
12, 69, 20	188	-114	-12	-97	-12.9	-7	0	-1	-6.7	64
15, 34, 10	375	-230	-46.7	-117	-15.6	-17	-2	-2	-8.1	64
15, 34, 20	387	-256	-37.6	-116	-15.5	-14	-2	-1	-8.1	64
15, 69, 10	231	-121	-21	-117	-15.6	-10	-1	-1	-8.1	64
15, 69, 20	234	-132	-16	-116	-15.6	-8	-1	-1	-8	64
18, 34, 10	447	-266	-55.7	-136	-18.2	-20	-3	-2	-9.5	64
18, 34, 20	460	-295	-45.2	-136	-18.2	-16	-2	-2	-9.4	64
18, 69, 10	278	-138	-26	-136	-18.3	-11	-1	-1	-9.4	64
18, 69, 20	281	-150	-20	-136	-18.3	-10	-1	-1	-9.4	64

* Changes in groundwater flow will be caused by (1) reservoir seepage, (2) elimination of farms within the reservoir footprint, and (3) operation of the seepage canal. Model showed no impact on STA 2, WCA 2, or WCA 3. Model showed very little impact to Compartment B or farms to the east.
** The farms located in the footprint of the reservoir currently remove 64 cfs from the groundwater system.

FIGURES

Figure 1 A-1 Reservoir Location

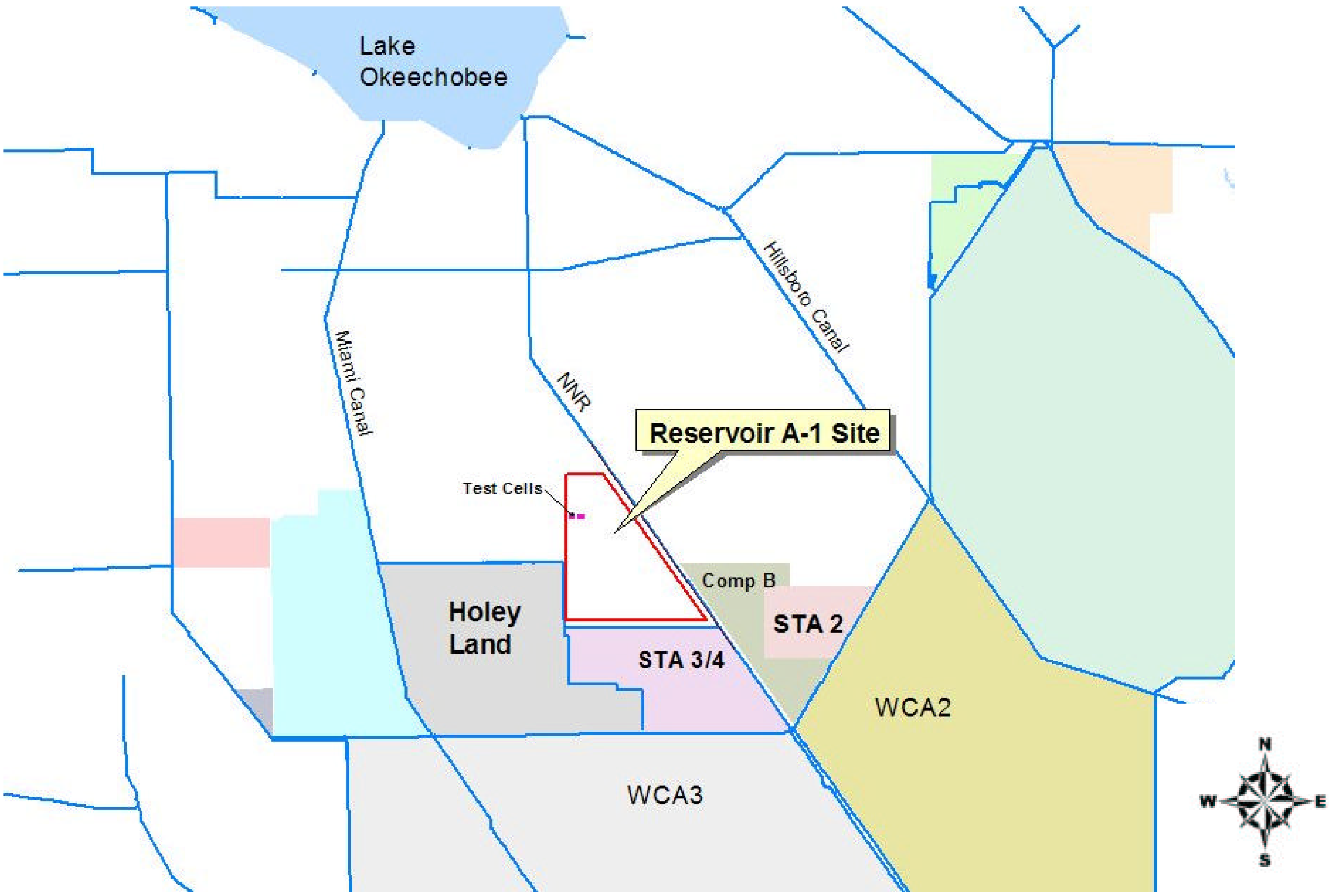


Figure 2 Example Reservoir Depth Fluctuation

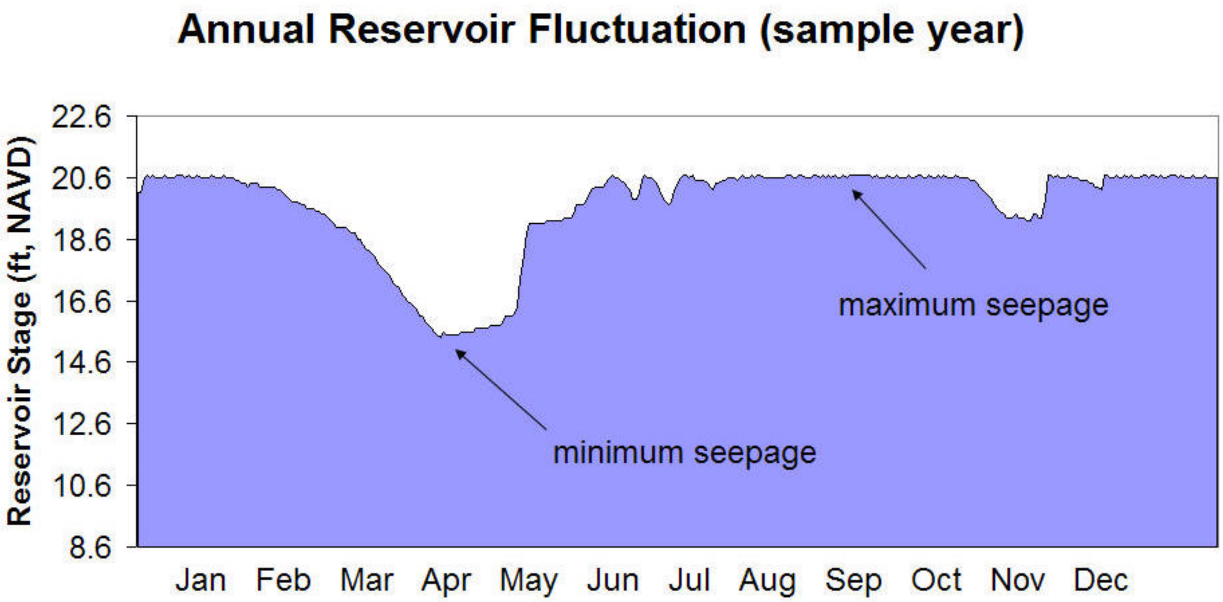


Figure 3 Anticipated Seepage Flow Paths

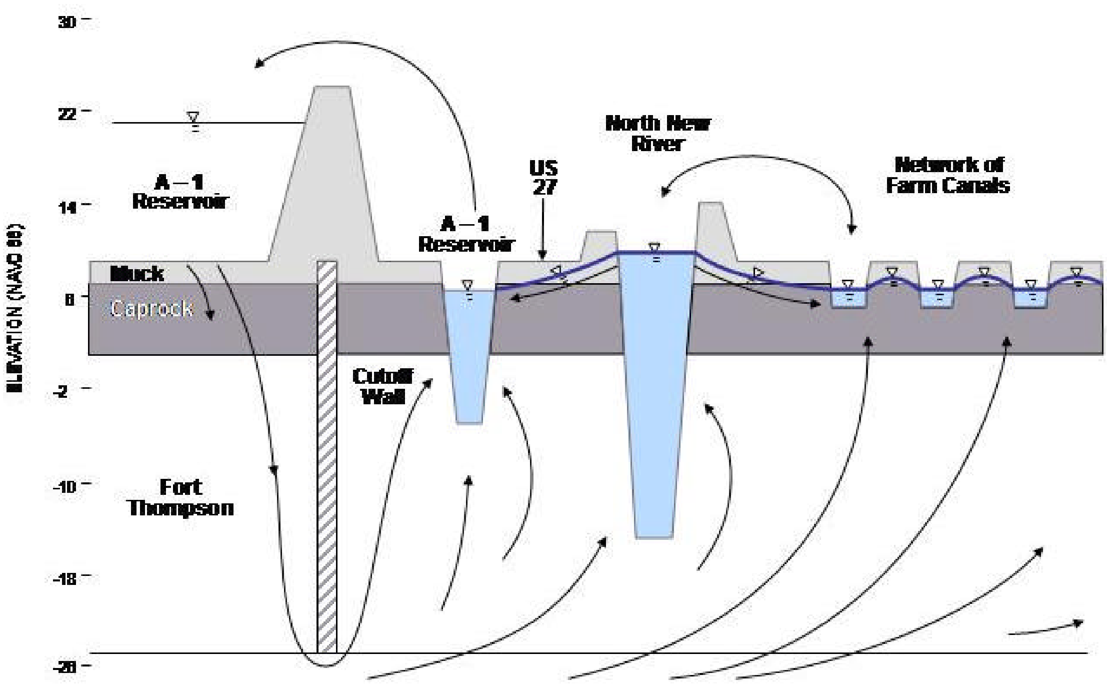


Figure 4 Extents of MODFLOW Model of EAA Reservoir A-1

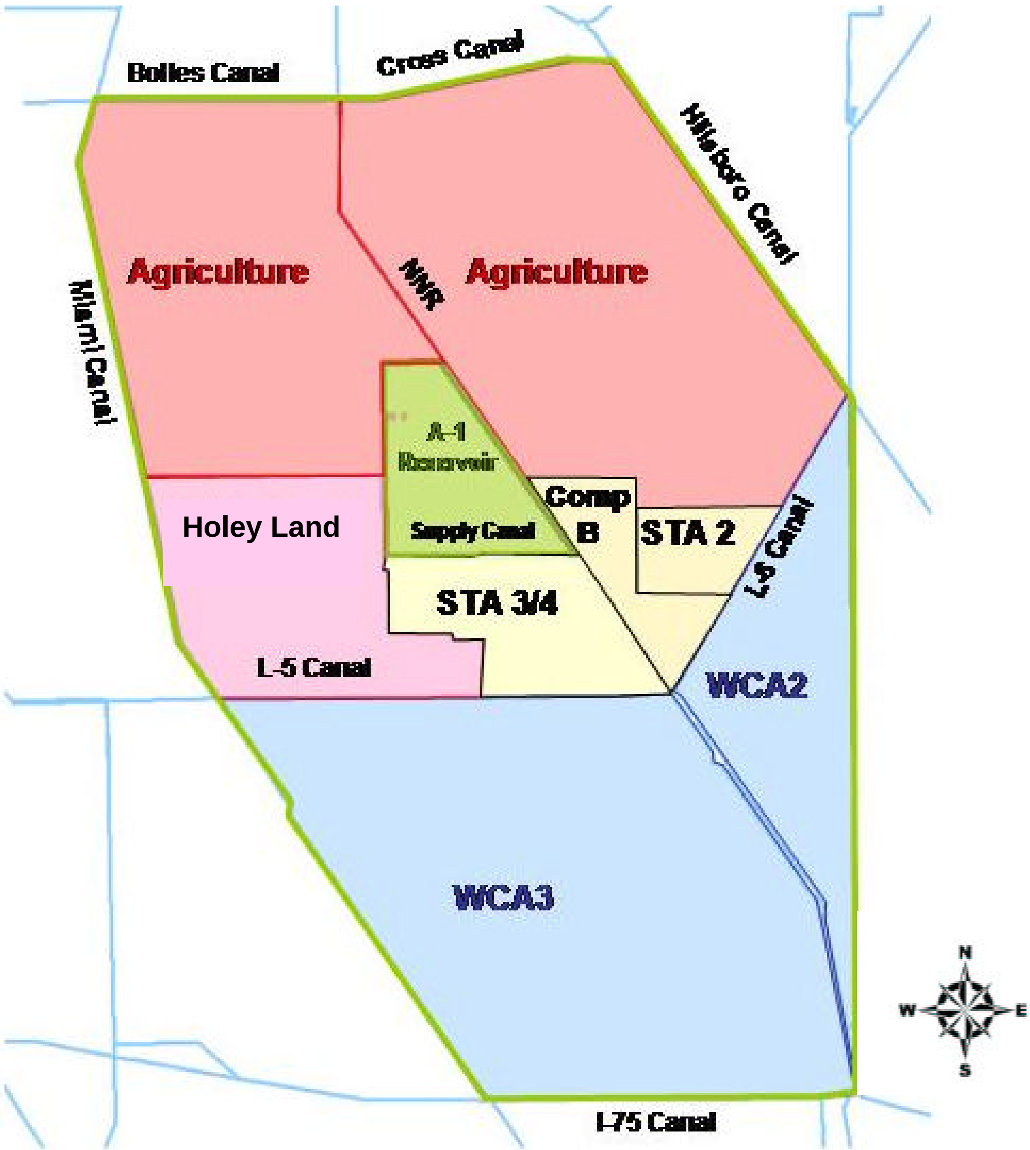


Figure 5 Stratigraphy for Reservoir A-1 MODFLOW Model

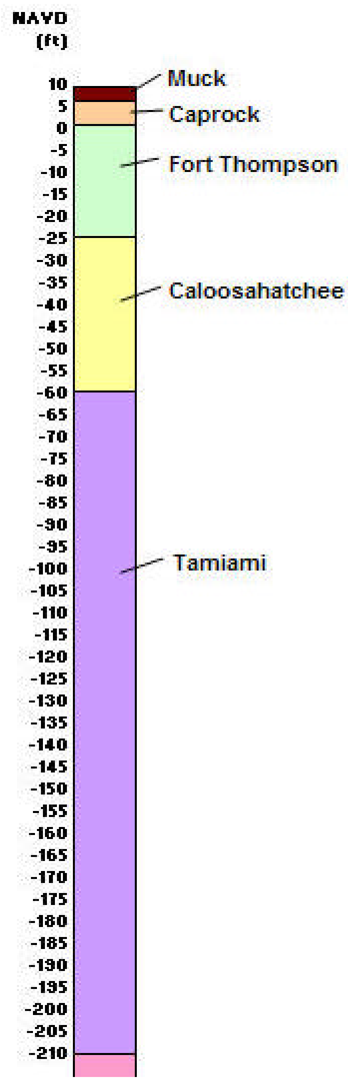
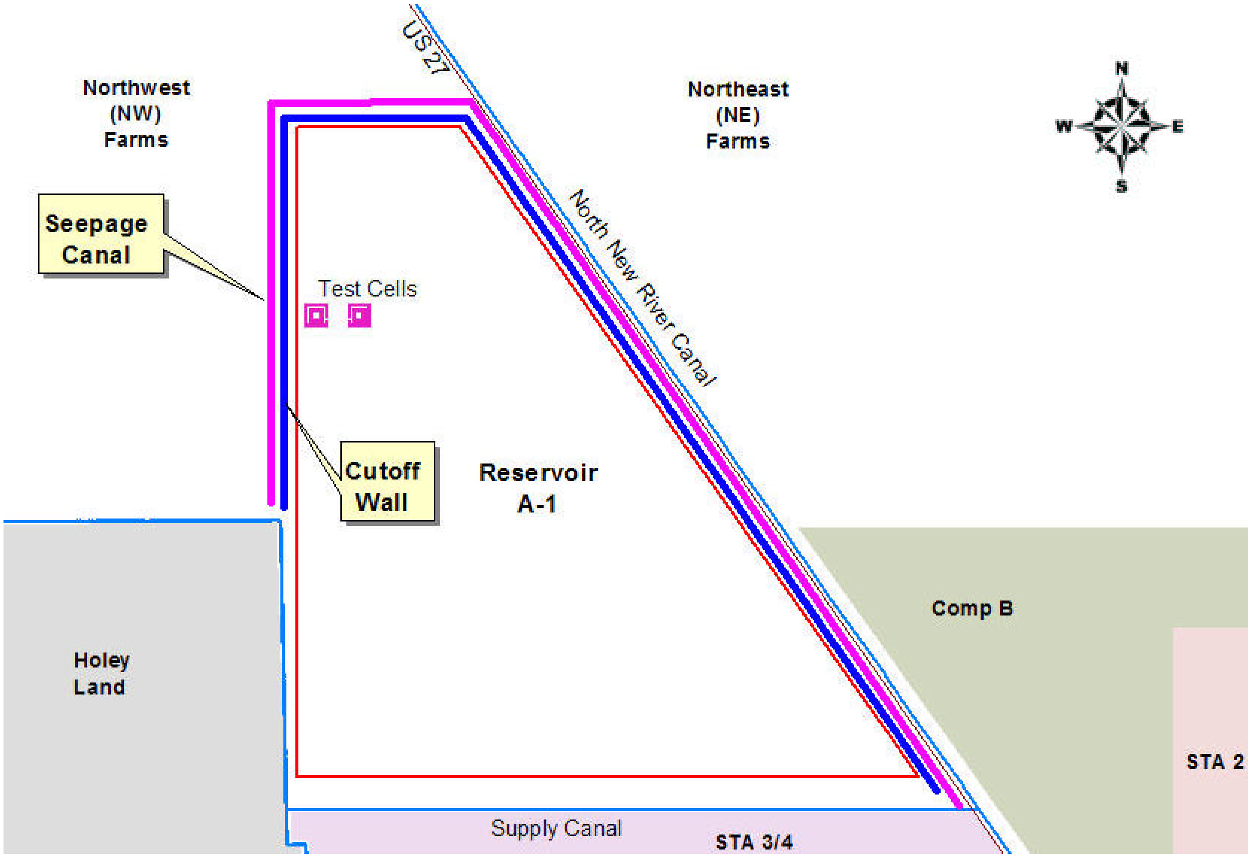
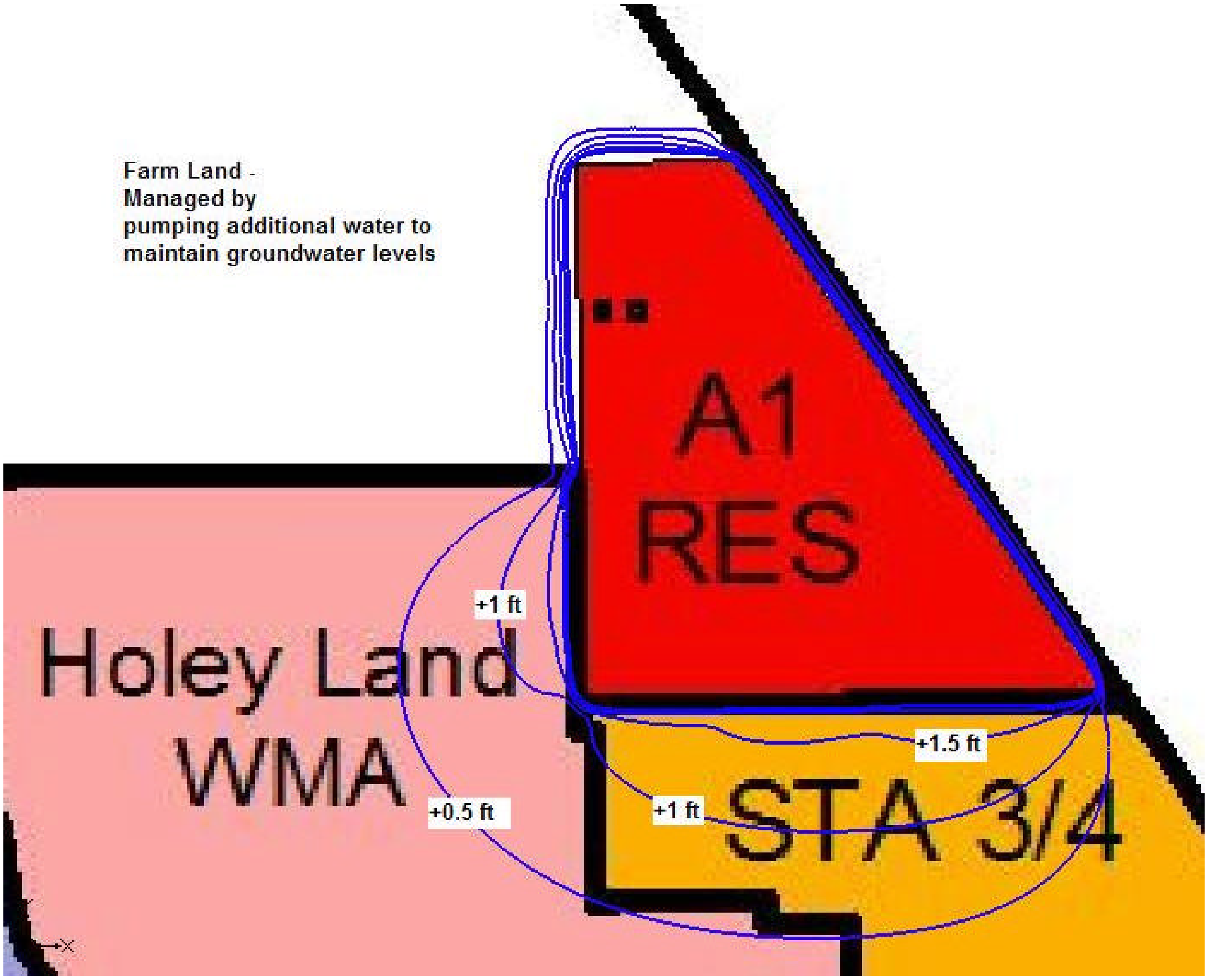


Figure 6-Simulated Locations of Seepage Collection Canal and Cutoff Wall



(Note: A shallow cutoff wall of 10 feet was incorporated along STA 3/4 and the Holey Land)

Figure 7 Predicted Rise in Groundwater Levels Caused by Seepage



Reservoir Water Depth = 12 feet
Cutoff Wall Depth along North, Northwest, and East Sides = 34 feet bgs
Seepage Canal Depth along North, Northwest, and East Sides = 10 feet bgs
Cutoff Wall Depth along Sides Adjacent to Holey Land and STA 3/4 = 10 feet bgs
No Seepage Canal along Holey Land and STA 3/4

Notes:

1. This assumes the reservoir maintains a water depth of 12 feet indefinitely with no seepage canal and a shallow 10-ft cutoff wall along the embankment adjacent to STA 3/4 and the Holey Land.
2. This assumes STA 3/4 and the Holey Land cannot be managed to offset rising water levels caused by seepage. In reality, when seepage occurs, less water could be discharged to these areas from the canals to offset seepage.